

Table 1. Water level, well depth, and specific capacity of wells installed in regolith in the Mississippian carbonate aquifer and model recharge dates of selected samples, 2000-2001

[NGVD, National Geodetic Vertical Datum; <, less than; --, no data; Modern, model recharge dates that are post-1997]

Well number	Station number	Date	Water level, in feet below land surface	Well Depth, in feet below land surface	Elevation, in feet above NGVD 29	Specific capacity, in gallons per minute per foot of drawdown	Model recharge date (data in appendix 2)
1	353341086074501	05/30/00	12.4	43	1,097	<0.01	--
2	352627086002601	05/30/00	7.91	15	1,098	<0.01	--
3	354014086093401	05/30/00	16.8	43.5	1,250	<0.01	--
4	350709086120701	06/06/00	48.15	51	958	2.13	--
5	351646086040701	05/30/00	34.74	43.5	1,018	<0.01	--
6	351459085555901	06/05/00	13.46	23	1,030	<0.01	--
7	351118086051801	06/05/00	68.95	73.5	950	1.43	1997
8	350203086391701	05/31/00	8.85	29	950	0.01	--
9	344407086273401	06/01/00	35.2	37	760	0.03	--
10	345539086241301	05/31/00	22.4	53	790	0.01	--
11	345822086254001	06/06/00	23.4	50	858	0.13	1996
12	345222086303301	06/07/00	72.76	79	765	7.92	Modern
13	345112086313401	06/01/00	24.6	35	705	0.23	1994
14	345247086415001	05/31/00	26.25	39.5	822	0.02	1992
16	345912086243901	05/31/00	16.55	30	845	0.13	--
17	344553086591301	05/25/00	13.9	38	697	<0.01	--
18	344124086531401	05/24/00	16.9	24	612	0.03	--
19	344439086532001	04/16/01	9.23	23	662	0.02	--
20	343836086562901	05/25/00	22.01	33	580	0.19	1997
21	344042086504301	04/16/01	26.78	32	608	0.05	--
22	344127087212001	05/23/00	3.63	55	593	<0.01	--
23	343919087182201	05/24/00	20.65	43.5	574	<0.01	--
24	344154087171201	05/24/00	5.4	14	565	0.85	--
25	344343087220101	05/24/00	7.05	53	550	0.47	1969
26	344557087253201	04/17/01	28.3	31.5	543	0.08	--
27	344217087283601	04/17/00	43.15	46	585	0.21	--
28	344036087320901	05/22/00	24.2	28	567	<0.01	--
31	344615086272201	06/01/00	19.37	36	663	0.11	--
33	344131087335201	05/22/00	22.97	53	538	0.04	1978
34	343530086213801	06/01/00	10.9	23	595	<0.01	--
35	344348086493401	05/25/00	42.25	53	640	2.85	1997
36	343613086441701	05/25/00	8.2	24.5	560	0.04	--

Land Use and Soils

Cropland accounted for about 16 percent of the land cover in the Eastern Highland Rim in 1992 (Kingsbury and others, 1999), with much of the cropland concentrated along the Tennessee River in northern Alabama (fig. 2). Cotton, corn, soybeans, and winter wheat are the principal crops grown in the Eastern Highland Rim. A total of about 441,000 acres of these crops were harvested in 2000 (U.S. Department of Agriculture, 2001c). Cotton accounted for 43 percent of this acreage. Various cropping systems are used throughout the area, with significant crop rotation occurring; as a result, this study did not target a specific crop with respect to its effect on shallow groundwater quality.

The amount of cropland in buffer areas around the monitoring wells ranged from 20 to 100 percent, with a median of 63 percent (table 2). The majority of monitoring wells had some cotton and corn in the buffer area; however, wells with greater than about 50 percent cropland in the buffer area typically were dominated by cotton (fig. 4). Cotton acreage was more prevalent around wells located in northern Alabama. Winter wheat and soybeans were present in buffer areas surrounding 12 and 7 of the wells, respectively, and typically represented less than 10 percent of the buffer area (table 2). Buffer areas around many of the wells included both conventional till and no-till fields. Only 6 of the 32 wells had buffer areas that included irrigated fields.

Many of the soil characteristics delineated in buffer areas are correlated to one another (table 3). Soils in the study area are predominantly silt loams and cherty silt loams. The soils are moderately well to well-drained, with an average slope of about 3 percent and organic matter content of less than 3 percent. Soil hydrologic group and drainage class, two variables that describe the movement of water through soil, are correlated to clay content and soil pH and are

inversely related to organic matter content (table 3). The percentage of soil hydrologic group B and the percentage of well-drained soil are strongly correlated (table 3), so the amount of well-drained soil in the buffer areas was the principal soil characteristic used for data analysis. Given that the soil characteristics are not independent, discerning the effect of specific soil characteristics on water quality is difficult.

Land use is related to the soil properties near the wells. Most notably, the percentage of cotton, as well as the percentage of cropland, in buffer areas tends to be greater where soils are predominantly well-drained (fig. 4). Although not statistically significant at the 95-percent confidence level, the amount of corn near the wells is inversely related to the amount of well-drained soil in the buffer areas. Soils also are less well drained and have higher organic matter content in areas with larger amounts of forest land. The strong correlations between soil characteristics and land use including the types of crops (and, therefore, the types of pesticides used) confound analysis of the effects of soil properties on nitrate and pesticide occurrence in this area.

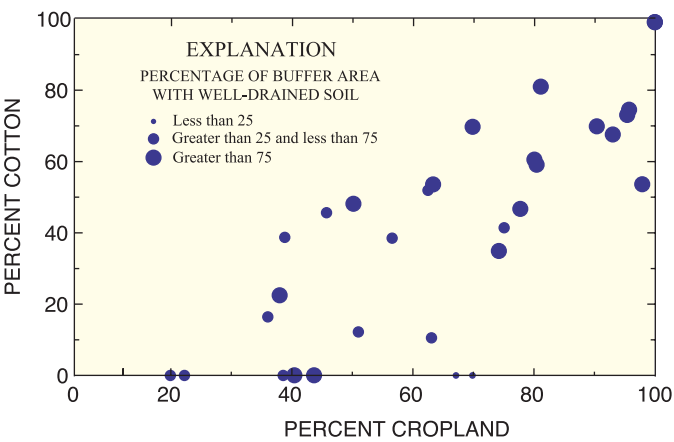


Figure 4. Percentage of cotton, cropland, and well-drained soils in buffer areas around land-use monitoring wells in the Mississippian carbonate aquifer.

Table 2. Summary of major land uses in buffer areas of wells in agricultural areas in the Eastern Highland Rim, 2000

[Values in percent; N, number of wells with a particular land use in the buffer area]

	Cotton	Corn	Soybeans	Winter wheat	Cropland (total)	Hay and pasture	Urban	Forest
Minimum	11	2	7	2	20	3	1	2
Median	50	15	10	8	63	38	8	12
Maximum	100	58	16	41	100	61	43	47
N	24	21	7	12	32	20	21	26

Table 3. Spearman's correlation coefficient, rho, for soil characteristics in buffer areas around wells[Spearman's rho bolded indicates significance at $p < 0.05$ and italics indicates $p < 0.10$; <, less than]

	Slope	Percent hydro-logic group B	Percent well drained	Percent sand	Percent silt	Percent clay	Available water capacity	Bulk density	Organic matter	Permeability	pH
Slope	1.00	<i>0.30</i>	0.28	0.27	-0.59	0.48	<i>0.35</i>	<i>0.30</i>	0.04	0.07	0.54
Percent hydrologic group B		1.00	0.99	0.20	-0.00	0.44	-0.19	-0.35	-0.50	-0.13	0.48
Percent well drained			1.00	0.22	-0.02	0.46	-0.17	-0.35	-0.50	-0.16	0.53
Percent sand				1.00	-0.58	0.07	-0.20	0.20	0.02	-0.33	0.15
Percent silt					1.00	-0.54	0.67	-0.22	-0.15	0.08	-0.36
Percent clay						1.00	-0.67	-0.28	-0.28	-0.13	0.43
Available water capacity							1.00	0.03	0.06	-0.06	-0.11
Bulk density								1.00	0.46	0.18	0.03
Organic matter									1.00	<i>0.32</i>	-0.10
Permeability										1.00	-0.12
pH											1.00

The specific capacity and depth to water in the monitoring wells also were correlated to soil properties in the buffer areas. In areas with higher percentages of well-drained soils in the buffer areas, the depth to water generally increased as did the specific capacity of water in a well.

SHALLOW GROUND-WATER QUALITY IN AGRICULTURAL AREAS

Wells were sampled for major inorganic constituents, nutrients (nitrogen and phosphorus species), pesticides, and selected pesticide degradates. Nitrate typically is the most important nutrient in ground-water systems because of its potential effects on human health, solubility, and stability in oxic ground water; therefore, discussion of nutrients in this report is limited to nitrate. A large number of pesticides were analyzed in the samples collected (appendix 1); however, not all of them have significant use in the study area. Pesticides that were analyzed and detected, or are used extensively in the study area, are discussed in this report. Most of the wells were sampled in the early summer of 2000 (table 4). Four wells that were dry during the summer of 2000 were sampled in April 2001, and five wells were resampled to evaluate whether constituent concentrations differed significantly between sampling periods. Rainfall for the 12-month period prior to both sampling periods was about 9 inches below the 30-year average annual rainfall

(AWIS Weather Services, Inc., written commun., 2001).

Major inorganic constituents and field properties did not vary substantially for four of the five wells that were resampled in 2001 (table 4). Differences in constituent concentrations between years typically were not greater than the variability associated with sampling and analysis as indicated by replicate samples. Calcium and alkalinity varied by more than 15 percent in the samples collected from well 35 (table 4), but other constituents in these samples did not vary substantially. Given the small amount of variability in major inorganic constituent concentrations between the sample periods, nitrate and pesticide data for the four wells sampled in 2001 are included with the data for the 28 samples from 2000.

About two-thirds of the samples collected were calcium bicarbonate water. In a few samples, particularly in low ionic strength samples (specific conductance less than 100 $\mu\text{S}/\text{cm}$), nitrate and chloride replaced bicarbonate as the dominant anion, and there was not a dominant cation in most of these samples. Samples from wells installed in regolith overlying the Fort Payne Chert had lower specific conductance and lower concentrations of constituents that are contributed from carbonate mineral dissolution, such as calcium and alkalinity, than samples from wells installed in regolith overlying the Tusculum Limestone (table 4). These differences for samples from wells in the Fort Payne Chert likely are the result of a greater amount of siliceous material in this formation than in

the Tuscumbia and Monteagle Limestones. The two samples with the highest specific conductance were completed in regolith overlying the Monteagle Limestone (table 4).

Dissolved-oxygen (DO) concentrations for most of the samples were greater than 1 mg/L (table 4) and were correlated to several factors. DO concentrations were positively correlated to the amount of well-drained soil in the buffer areas (Spearman's rho=0.31, p=0.04). DO concentrations also tended to increase with depth to water (fig. 5). This somewhat atypical relation between DO and water level likely is a result of the hydraulic connection of water in wells completed in deep regolith to oxic water in the bedrock part of the aquifer. These deep wells generally had the highest specific capacities (table 1). Although the median DO concentration was lower in samples from the Tuscumbia Limestone than from the Fort Payne Chert (table 4), the difference was not statistically significant. DO concentrations were inversely related to the amount of forest land and positively related to the amount of agricultural land (cropland plus pasture) in the buffer area around wells. The inverse relation of DO to the amount of forest land in the buffer area likely is a result of a lower percentage of well-drained soils in forested areas related to greater amounts of respiration by soil microbes in forested areas.

Chloride concentrations were positively correlated with DO (Spearman's rho=0.44, p=0.01), indicating that much of the chloride in the aquifer is transported from the surface with recharge rather than originating from dissolution of the carbonate rock. Median chloride concentrations were not statistically different for wells overlying the Tuscumbia Limestone and Fort Payne Chert; however, concentrations were

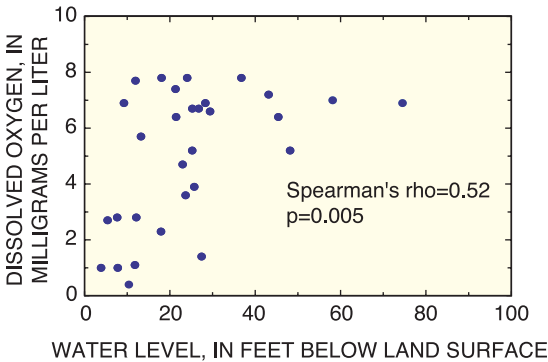


Figure 5. Relation between dissolved-oxygen concentration and water level in agricultural monitoring wells in the Mississippian carbonate aquifer.

considerably higher in the two wells completed in regolith overlying the Monteagle Limestone (table 4). The high concentrations of chloride in these two samples may reflect differences in the composition of this formation. Chloride can be contributed to ground water from numerous sources at land surface. Agricultural sources of chloride that could affect these wells include soil amendments such as potash (KCl) and sodium chlorate, a defoliant used on cotton.

The calcite saturation index is inversely related to DO concentrations, which may indicate relative differences in average ground-water residence times for some samples, particularly from wells completed in the Tuscumbia Limestone (fig. 6). The calcite saturation index relates the concentrations of calcium and

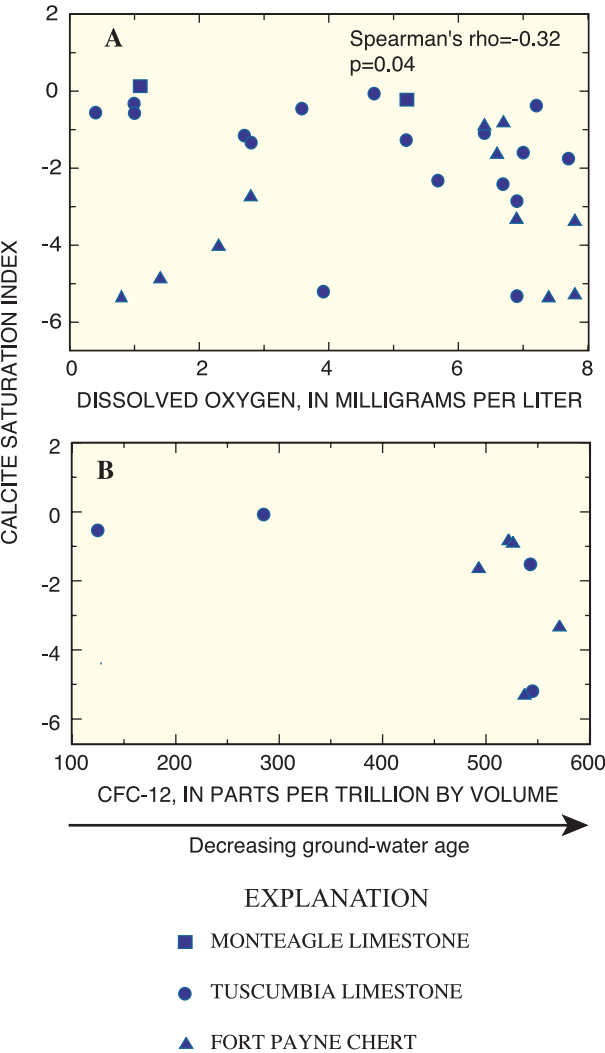


Figure 6. (A) Relation between dissolved-oxygen concentration and calcite saturation index and (B) young model ground-water ages as indicated by CFC-12 concentrations coincided with low calcite saturation indices in samples from the Mississippian carbonate aquifer.

Table 4. Water-quality properties and major inorganic constituent concentrations in samples from 32 wells in the Mississippian carbonate aquifer, 2000-2001

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; E, estimated; --, no data; median values by geologic units do not include the second sample for wells with two samples]

		Field specific			Solids			Cal-		Mag-		Potas-		Chlo-		Manga-			
		Field pH	con-	Dis-	Field	residue	Hard-	cium-	nesium,	Sodium,	Sodium,	Sulfate,	Silica,	Iron,	nese,	Nitrate,			
Well	Date	(stand-	ductance	solved	alka-	at 180 °C	ness, total	dis-	dis-	dis-	dis-	dis-	dis-	dis-	dis-	dis-	Calcite		
number	sampled	ard units)	(μS/cm at	oxygen	linity	dis-	(mg/L as	solved	solved	solved	solved	solved	solved	solved	solved	solved	satu-		
			25 °C)	(mg/L)	(mg/L as	(mg/L)	(mg/L as	(mg/L as	(mg/L	(mg/L	(mg/L as	(mg/L	(mg/L	(mg/L as	(μg/L	(μg/L as	(mg/L	ration	
					CaCO ₃)		CaCO ₃)	CaCO ₃)	as Ca)	as Mg)	Na)	as K)	as Cl)	SO ₄)	as SiO ₂)	as Fe)	Mn)	as N)	index
Fort Payne Formation																			
1	05/30/00	6.4	137	2.8	69	79	8	2.3	0.44	14	18	0.7	3.7	5.9	<10	5,060	< 0.05	-2.75	
3	05/30/00	5.5	38	2.3	17	22	12	3.5	0.67	0.7	0.6	0.6	E0.3	9.4	600	1,430	0.25	-4.03	
8	05/31/00	4.8	45	0.8	7	23	7	1.7	0.62	4.0	0.4	3.8	2.4	9.3	1,220	373	0.72	-5.36	
10	05/31/00	5.3	32	1.4	7	18	7	2.0	0.48	1.5	0.4	3.8	E0.2	9.3	760	61	0.18	-4.87	
11	06/06/00	4.6	66	7.8	4	61	20	5.1	1.7	1.9	0.9	4.3	0.4	7.7	E10	44	5.0	-5.30	
11	04/19/01	4.9	67	7.7	8	58	20	5.2	1.8	1.7	1.1	4.4	0.3	7.8	<10	40	4.8	-4.82	
12	06/07/00	5.6	93	6.9	26	69	36	10	2.7	1.2	2.2	2.8	E0.3	8.7	<10	151	3.8	-3.33	
13	06/01/00	7.1	248	6.7	96	140	120	28	12	1.1	0.5	5.7	0.5	8	<10	108	3.3	-0.83	
13	04/18/01	6.8	215	7.2	91	110	110	25	11	1.5	0.4	5.1	0.5	8.1	<10	E2	3.2	-1.28	
14	05/31/00	6.7	123	6.6	54	72	58	17	3.8	1.4	E0.2	2.9	1	7.6	<10	E2	0.81	-1.63	
16	05/31/00	5.5	104	7.8	23	74	41	14	1.7	1.4	0.5	5.0	4.8	8	<10	239	3.2	-3.39	
31	06/01/00	4.9	60	7.4	4	42	14	2.9	1.7	4.4	0.8	5.6	1.7	8.1	<10	83	3.3	-5.37	
31	04/18/01	5.1	60	6.9	9	52	16	3.3	1.8	3.4	1	5.5	1.1	8.3	<10	83	3.5	-4.77	
35	05/25/00	6.7	295	6.4	136	170	140	47	5.6	1.7	1	2.9	1.2	8.2	<10	3	2.7	-0.89	
35	04/17/01	6.9	220	7.9	92	131	110	35	4.5	1.6	0.7	2.7	0.9	8	<10	3	3.1	-1.03	
Median of 11 samples		5.5	93	6.6	23	69	20	5.14	1.72	1.5	0.6	3.8	1	8.1	<10	108	2.71	-3.39	
Tuscumbia Limestone																			
2	05/30/00	6.1	131	5.7	50	82	64	19	4.1	1.6	1.1	3.0	4	6.8	E10	94	2.2	-2.31	
4	06/06/00	6.6	245	5.2	106	140	110	34	7.0	1.5	0.5	4.2	4	7.6	<10	5	2.6	-1.25	
5	05/30/00	7.0	264	--	115	158	130	48	2.0	4.7	0.8	1.2	7.6	8.4	<10	71	0.12	-0.66	
6	06/05/00	6.8	178	7.7	39	127	70	17	6.7	4.1	0.7	9.7	2	8.4	<10	3	8.5	-1.74	
7	06/05/00	6.2	263	7	99	162	120	39	4.5	1.7	0.7	6.9	2.7	6.9	<10	7	4.8	-1.58	

Table 4. Water-quality properties and major inorganic constituent concentrations in samples from 32 wells in the Mississippian carbonate aquifer, 2000-2001—Continued

Well number	Date sampled	Field pH (standard units)	Field specific conductance (μS/cm at 25 °C)	Dis-solved oxygen (mg/L)	Field alkalinity (mg/L as CaCO ₃)	Solids residue at 180 °C dis-solved (mg/L)	Hardness, total (mg/L as CaCO ₃)	Calcium, dis-solved (mg/L as Ca)	Magnesium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potassium, dis-solved (mg/L as K)	Chloride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO ₄)	Silica, dis-solved (mg/L as SiO ₂)	Iron, dis-solved (μg/L as Fe)	Manganese, dis-solved (μg/L as Mn)	Nitrate, dis-solved (mg/L as N)	Calcite saturation index
Tuscumbia Limestone—Continued																		
9	06/01/00	6.3	156	--	51	94	73	16	8.2	1.8	0.5	5.6	1.2	6.3	<10	117	5.7	-2.33
17	05/25/00	7.2	122	2.8	50	72	53	15	4.0	2.4	0.6	1.2	9.8	5.3	<10	2,590	0.07	-1.34
18	05/24/00	6.6	258	6.4	115	150	120	43	3.7	1.4	0.8	2.0	3.4	6.5	<10	<2	3.37	-1.05
19	04/16/01	5.1	22	6.9	6	28	5	1.1	0.55	1.7	0.3	4.0	0.2	9.7	10	45	0.15	-5.35
20	05/25/00	5.0	39	3.9	8	36	12	3.3	1.0	1.4	0.7	1.3	2.8	8.6	E10	437	1.0	-5.20
21	04/16/01	6.1	147	6.7	35	99	64	20	3.3	2.1	0.7	2.8	1.7	8.2	E10	12	7.7	-2.41
22	05/23/00	7.2	455	1	207	265	240	85	6.4	4.8	0.5	0.8	5.6	8.1	40	438	< 0.05	-0.34
23	05/24/00	7.0	312	3.6	153	201	170	60	4.0	5.1	0.4	1.4	11	8.4	<10	9	0.56	-0.47
24	05/24/00	6.5	273	2.7	135	158	140	51	3.0	1.6	2.5	2.8	3.1	4.1	<10	67	0.87	-1.16
25	05/24/00	7.0	351	0.4	165	206	190	68	3.7	2.1	0.5	3.7	2.9	8.1	<10	177	0.32	-0.54
26	04/17/01	5.9	76	6.9	38	63	37	11	2.2	0.9	0.4	1.5	0.2	9	30	63	0.44	-2.84
27	04/17/01	7.0	423	7.2	172	257	200	76	2.7	5.0	0.9	19	0.9	9.5	<10	3	4.1	-0.35
33	05/22/00	7.6	259	4.7	118	162	120	46	1.7	1.7	0.5	3.0	1.9	8.7	<10	E2	3.7	-0.07
33	04/18/01	7.4	263	4.9	113	179	130	50	1.7	1.7	0.5	3.3	0.9	9	<10	3	4.5	-0.31
36	05/25/00	6.5	478	1	276	281	260	95	5.2	2.1	0.5	1.5	1.1	7.6	20	1,130	< 0.05	-0.57
Median of 19 samples		6.6	258	5.2	106	150	120	39	3.6	1.8	0.6	2.8	2.85	8.1	<10	63	1.01	-1.25
Monteagle Limestone																		
28	05/22/00	6.6	714	5.2	340	402	340	123	8.5	19	0.4	20	6	8.2	<10	4	0.48	-0.23
34	06/01/00	7.1	816	1.1	366	490	340	122	8.5	40	0.7	26	41.4	13.5	<10	64	0.10	0.16

carbonate ions in solution to the solubility of calcite. The calcite saturation index is expressed as the logarithm of the ion activity product of bicarbonate and calcium divided by the solubility constant for calcite. Saturation indices were calculated using the geochemical modeling code PHREEQC (Parkhurst and Appelo, 1999). Saturation indices close to zero indicate water is near to saturation with respect to calcite. The degree of calcite saturation is a qualitative indicator of the contact time between the ground water and carbonate aquifer material. A small saturation index may indicate a short amount of contact time between the water and carbonate rock. As DO concentrations decrease, the calcite saturation index tends to be higher (fig. 6). As previously noted, differences in saturation indices also can be attributed to differences in the composition of bedrock as well as to ground-water residence time. Chert in both the Fort Payne Chert and the Tusculumbia Limestone could affect this relation and may account for the low calcite saturation indices for several samples also having low DO concentrations (fig. 6). For the small number of samples with CFC-12 age dates, a relation seems to exist between ground-water age and the calcite saturation index (fig. 6).

Nitrate

Nitrate concentrations generally were low with no samples exceeding the drinking-water maximum contaminant level (MCL) of 10 mg/L. The maximum concentration of nitrate (as N) was 8.4 mg/L, and the median concentration was about 1 mg/L. Nitrate and DO concentrations were strongly correlated (fig. 7); therefore, nitrate concentrations were correlated to many of the same variables to which DO was correlated. For example, nitrate concentrations increase with the depth to ground water in the wells as did DO concentrations. This relation contrasts with the typical relation of decreasing nitrate concentrations with increasing depth to the water table documented in other ground-water studies (Hallberg and Keeney, 1993). In this setting, increased depth to water in these regolith wells may reflect a hydraulic connection to oxic ground water in bedrock. These parts of the aquifer represent the active part of the flow system, where nitrate likely is more stable. Partial correlation analysis of variables related to both nitrate and DO indicates that DO concentration accounts for most of the variation in nitrate concentrations in ground water. Nitrate concentrations in four of the five wells sampled twice

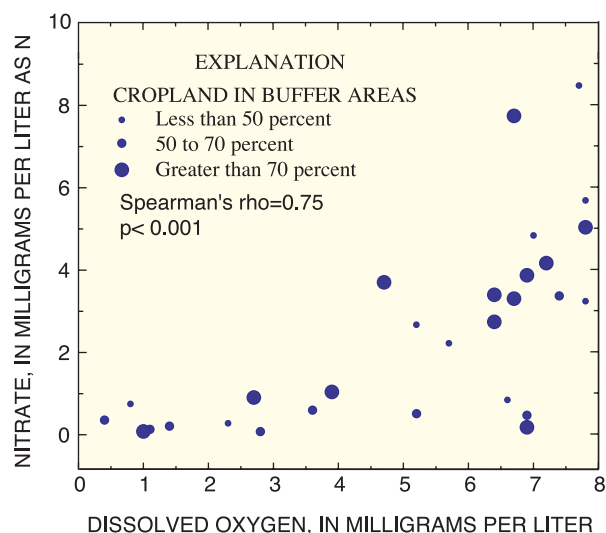


Figure 7. Nitrate and dissolved-oxygen concentrations for samples and cropland in buffer areas around wells in the Mississippian carbonate aquifer, 2000.

varied less than 5 percent (table 4), similar to the amount of variability between replicate samples. Nitrate concentrations were about 10 percent different in the two samples from well 33 (table 4).

The correlation of nitrate to DO suggests that nitrate concentrations are affected by denitrification and are low where either the average ground-water residence time is long or where recharge is slow as indicated by low DO concentrations. Nitrate and chloride concentrations are correlated and appear to be contributed to the aquifer predominantly from activities at land surface. Given that chloride is conserved in ground-water systems, the ratio of chloride to nitrate ($\text{Cl}:\text{NO}_3$) may indicate whether nitrate concentrations in samples are affected by denitrification. Samples with nitrate concentrations greater than 2 mg/L generally had DO concentrations greater than 6 mg/L and $\text{Cl}:\text{NO}_3$ ratios less than 2 (fig. 8). In contrast, samples with nitrate concentrations less than 1 mg/L tended to have lower DO concentrations and higher $\text{Cl}:\text{NO}_3$ ratios. Two samples with high $\text{Cl}:\text{NO}_3$ ratios were from wells completed in the Monteagle Limestone, and the elevated chloride in these samples may be from natural sources. Samples with nitrate concentrations less than 1 mg/L and a $\text{Cl}:\text{NO}_3$ greater than about 5 (fig. 8) likely represent samples from areas where denitrification is occurring. About a third of the samples fit these criteria. In addition, nitrate concentrations were inversely related to manganese concentrations (Spearman's $\rho=-0.5$, $p=0.002$). Dissolved manganese concentrations are greatly affected by the oxidation-reduction (redox) state of ground

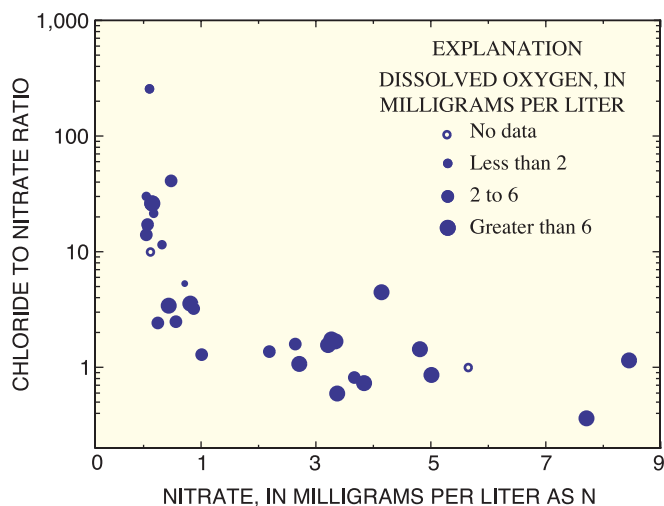


Figure 8. Relation between ratio of chloride to nitrate and nitrate concentrations in samples collected from the Mississippian carbonate aquifer.

water. The reactions that reduce manganese oxides to the soluble ionic form (Mn^{+2}) follow denitrification in the sequence of redox reactions (Stumm and Morgan, 1996). The inverse relation between nitrate and manganese concentration indicates that where nitrate concentrations are low, the redox conditions were favorable to denitrification.

Nitrate concentrations in the Eastern Highland Rim were lower than in other agricultural areas across the Nation. The median nitrate concentration for samples collected from 848 monitoring wells installed in agricultural areas in 30 NAWQA study areas across the Nation (fig. 9) was 2.3 mg/L compared to a median of about 1 mg/L for wells in this study (fig. 10). The NAWQA wells nationwide were sampled between 1991 and 2001 and ranged in depth from 7 to 200 ft with a median depth of 25 ft, compared to a median depth of 37.5 ft for the wells in this study. However, the interquartile range in nitrate concentration generally is comparable for the two data sets, and the nitrate concentration distributions are not statistically different (fig. 10). The maximum nitrate concentration measured in this study was equal to the 75th percentile in the NAWQA wells nationwide. About 21 percent of the samples from the wells nationwide equaled or exceeded the drinking-water MCL of 10 mg/L. No samples from the monitoring wells in the Mississippian carbonate aquifer exceeded the MCL.

Pesticides

Pesticides have increased the productivity of agricultural land in the Nation by controlling weeds,

fungi, insects, and nematodes, all of which can lower crop yields. Despite the increases in agricultural productivity and the associated economic benefits, a general concern exists about the effects of dispersing large quantities of potentially harmful pesticides into the environment. The fate of pesticides in the environment is influenced by many factors such as the method of application, physical and chemical properties of each pesticide, and numerous environmental factors. Pesticides typically are designed to degrade in a few days or weeks after application under ideal conditions. Degradation occurs by several processes including photolysis, hydrolysis, and biologically mediated reactions. Most of these processes occur more rapidly in the near-surface soil environment than in ground water. Movement of pesticides into ground-water systems may reduce the rate at which pesticides degrade, and pesticide residues may persist in ground water longer than in the soil zone. During the 1990s, numerous studies documented the importance of pesticide degradates in ground water (for example, Kolpin and others, 1998).

Of the 32 wells sampled, 29 (91 percent) contained one or more pesticides or pesticide degradates (fig. 11). Thirty-five different pesticides and pesticide degradates were detected (appendix 1), but 11 of them were detected in only one sample at concentrations below 0.01 $\mu\text{g/L}$, and are not included in the summary of detections (table 5). Atrazine, fluometuron, norflurazon, and their degradates were detected frequently and at the highest concentrations (table 5). No pesticide concentrations exceeded established MCLs for drinking water, but 32 of the 35 pesticides detected do not have MCLs. Degradates generally do not have MCLs. More than half of the samples contained 5 or more pesticides (fig. 11), and the maximum number of pesticides detected in a single sample was 13. The maximum concentration of a single pesticide was 3.21 $\mu\text{g/L}$ for demethylnorflurazon, a degradate of the cotton herbicide norflurazon (table 5). About half of the samples had a total pesticide concentration of 1 $\mu\text{g/L}$ or more (fig. 11), and the maximum total pesticide concentration measured in a sample was 7.2 $\mu\text{g/L}$.

The frequency of detection and magnitude of concentrations was related to the estimated use of pesticides (table 5). Atrazine, fluometuron, and norflurazon are among the most heavily used pesticides in the study area and were detected more frequently than pesticides with lower estimated use. Aldicarb, which